Magnetization and Flux Penetration of YBCO CORC Cable Segments at the Injection fields of Accelerator Magnets

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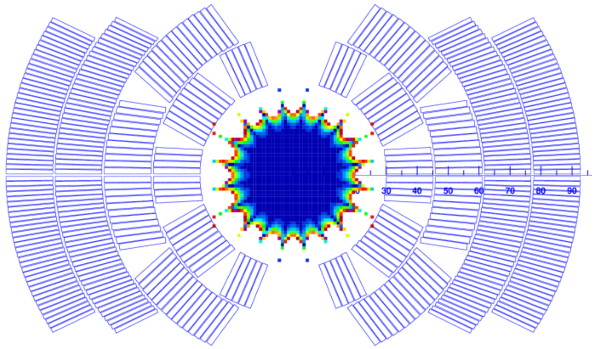
CSMM Center for Superconducting and Magnetic Materials

Department of Materials Science and Engineering

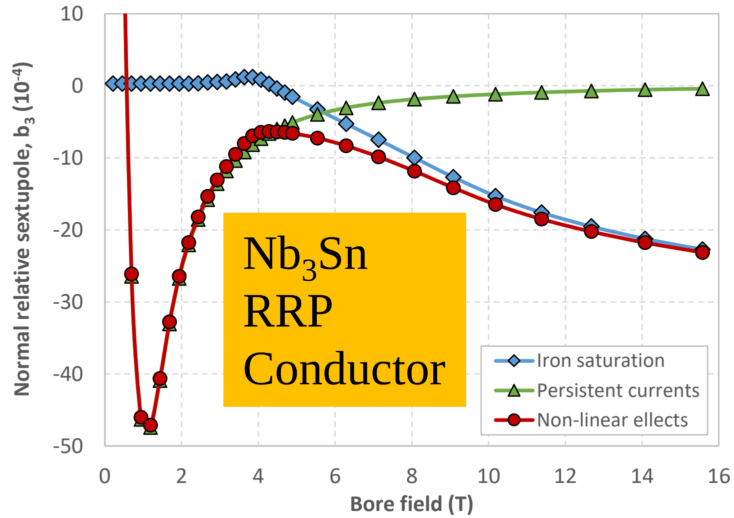
Outline of talk

- Motivation – accelerator quality
- Development of the Hall Probe Magnetometer and Calibration
- Samples Measured
- Measurement Results
- Application to accelerators

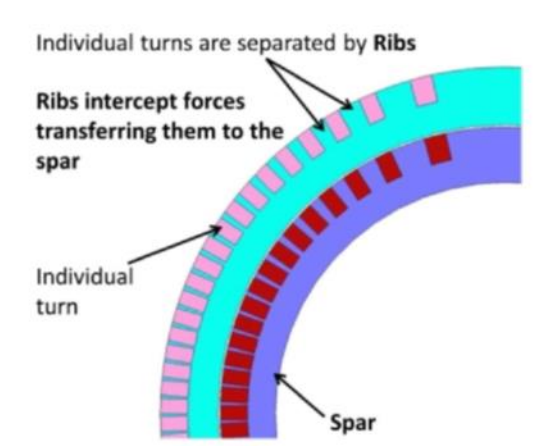
Motivation--Field Error in Accelerator Magnets



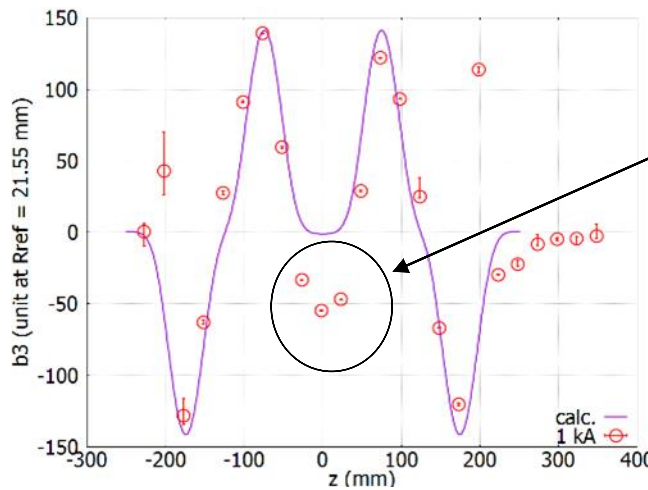
Cos theta



A Zlobin, “15 T dipole design concept, magnetic design and quench protection”, Presentation at the US MDP workshop Jan 2017



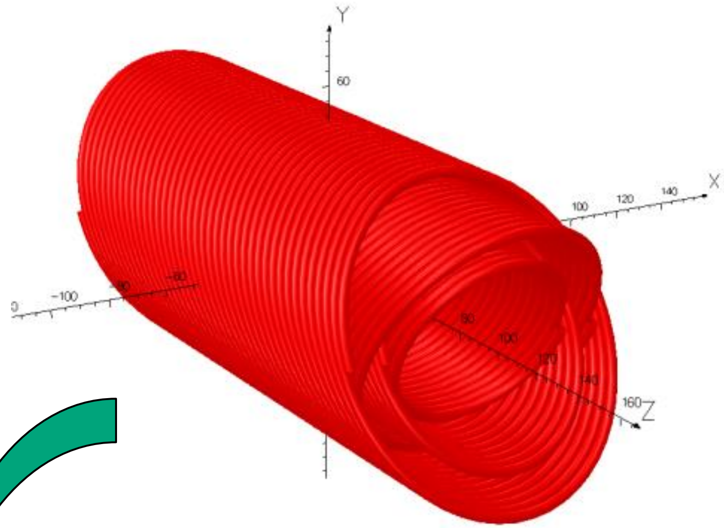
YBCO CORC Canted cos coil (Wang, LBNL 2018 MDP)



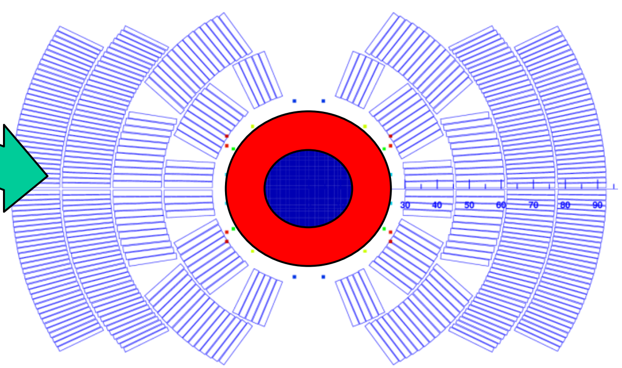
Magnetization related b3

LBNL Collaboration Canted Cos Dipole studies

X Wang/LBNL working on canted cos dipole using YBCO cable



X. Wang, "REBCO accelerator magnet development: status and plans", Presented at the USMDP NAPA, Jan 2017



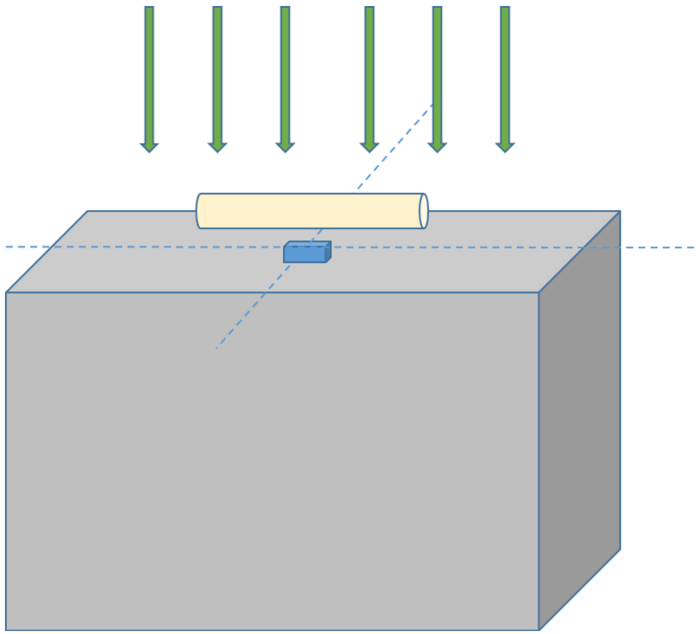
- As part of LBNL-OSU collaboration, Nb3Sn magnetization measurements and Bi:2212 magnetization data have been provided for error field calculations in other magnet designs
- This collaboration is expanded to include YBCO conductor and cable magnetization for magnets, and collaboration on error field determination
- **Cory Myers (OSU grad student) will perform a DOE grad student study program at LBNL working on field error**

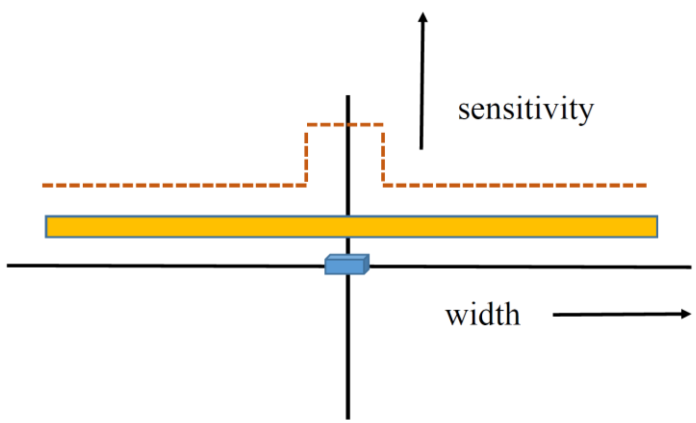
- If we consider for a moment the simplest case of an HTS insert in a background Nb3Sn magnet, then at injection, it may be reasonable to approximate field on CCT as a "uniform 1 T"
- **Initial error estimates using biot savart (and a doublet approach) suggest significant b3 for CCT wound with YBCO cables, as expected extrapolating from CCT1 > 25 unit**

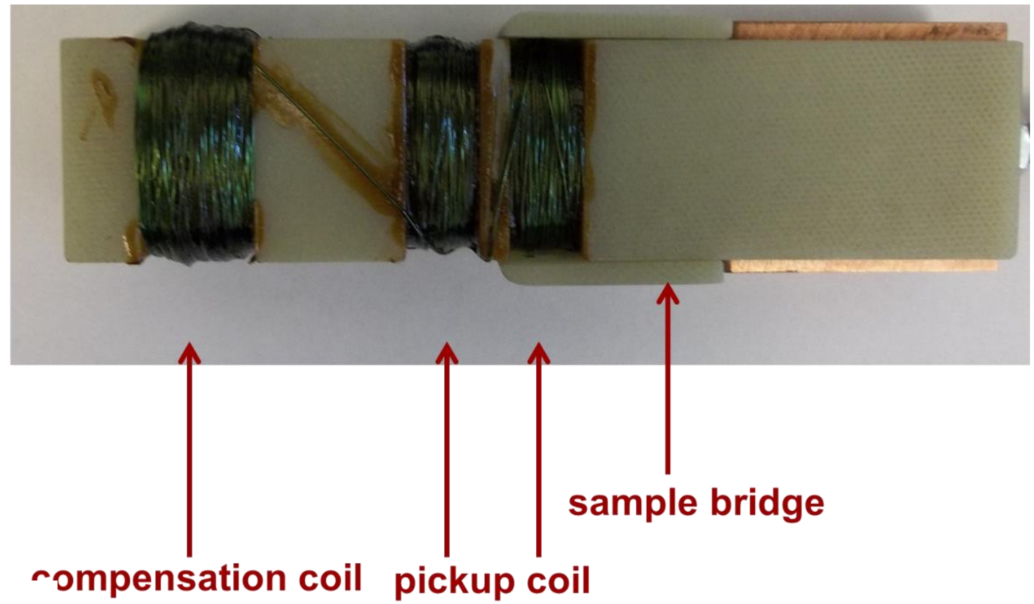
Hall Probe Magnetometer

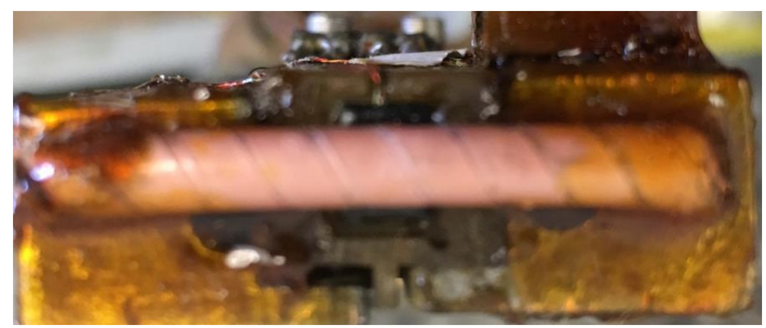
- Measurement made by ΔB between sample and no sample
- Field generated by 12 T, liquid cryogen free, RT bore magnet
- Cooling provided by varitemp dewar

Sample Mounting







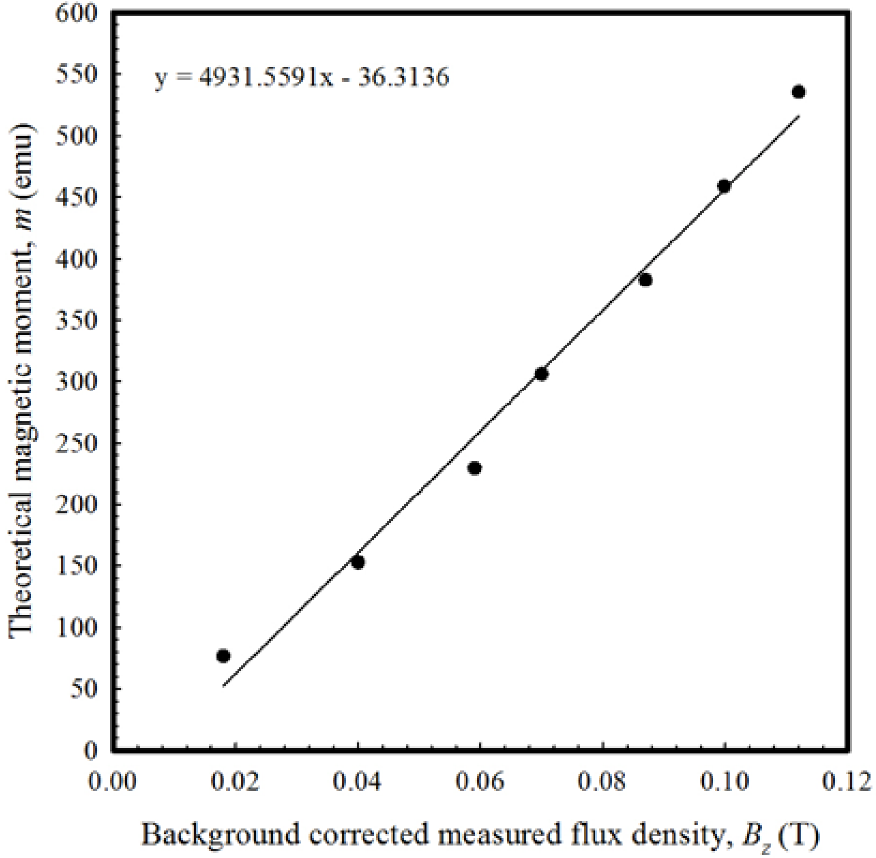


CORC Cable Measured

The Berkeley tape ID was 160823-Berkeley 250-C, used in their magnet C0a

Cable Properties	
Wire OD (mm)	3.21
Cu Core OD (mm)	2.34
No. Tapes	16
Tape width (mm)	2
Cu plating thickness (μm)	5
Substrate thickness (μm)	5
Cable Pitch (mm)	<6>
Sample Properties	
Sample Length (cm)	2.7
V_{cable} (cm^3)	218
V_{strand} (cm^3)	76.1

Ni standard Calibration



Calibration 1: ΔB $\rightarrow$m

$$B_z = C'\gamma m$$

or

$$m = \frac{B_z}{C'\gamma}$$

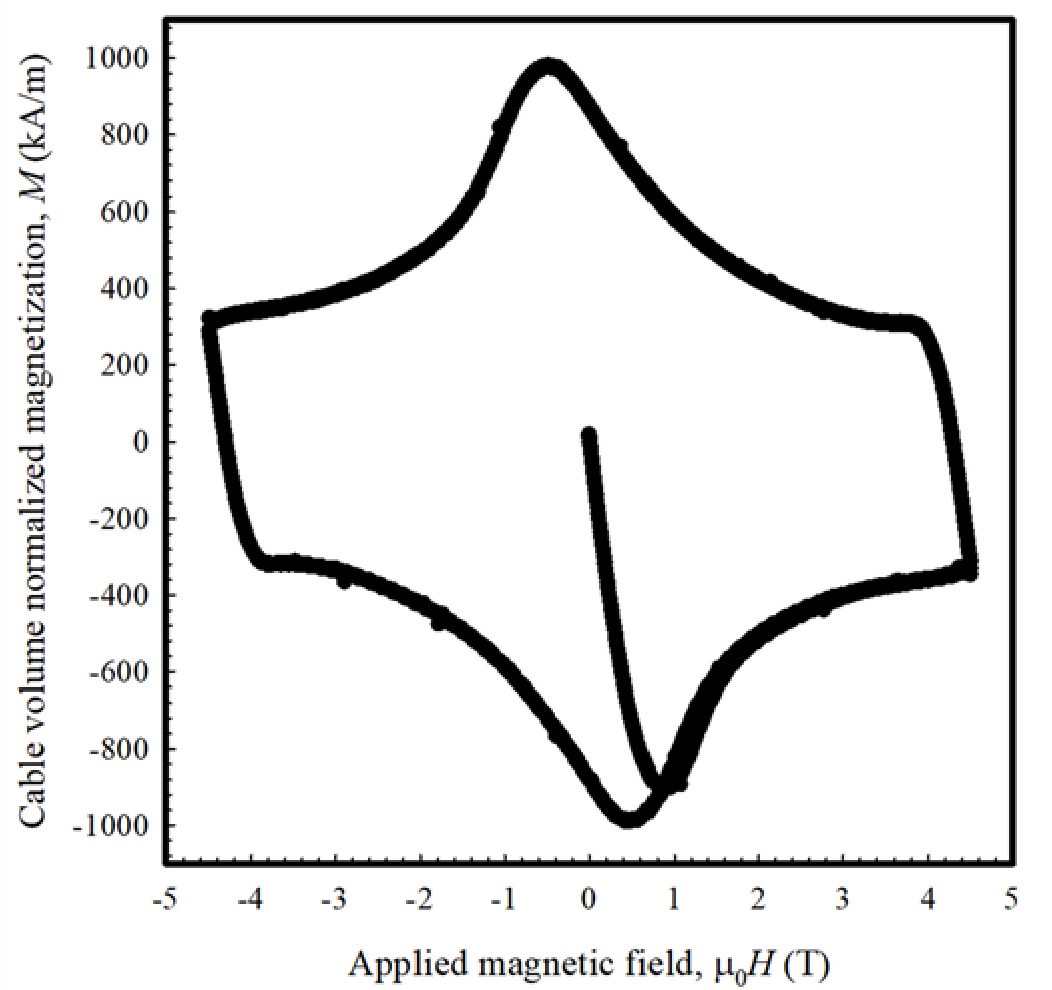
$1/C'\gamma = C/\gamma = 4931.6$ emu/T

Calibration 2: sensitivity factor

M-H curve should be -2. Doing this, we find $\gamma_{Ni\ tape}/\gamma_{CORC} = 0.1$, or $\gamma_{CORC} = 10\ \gamma_{Nitape}$

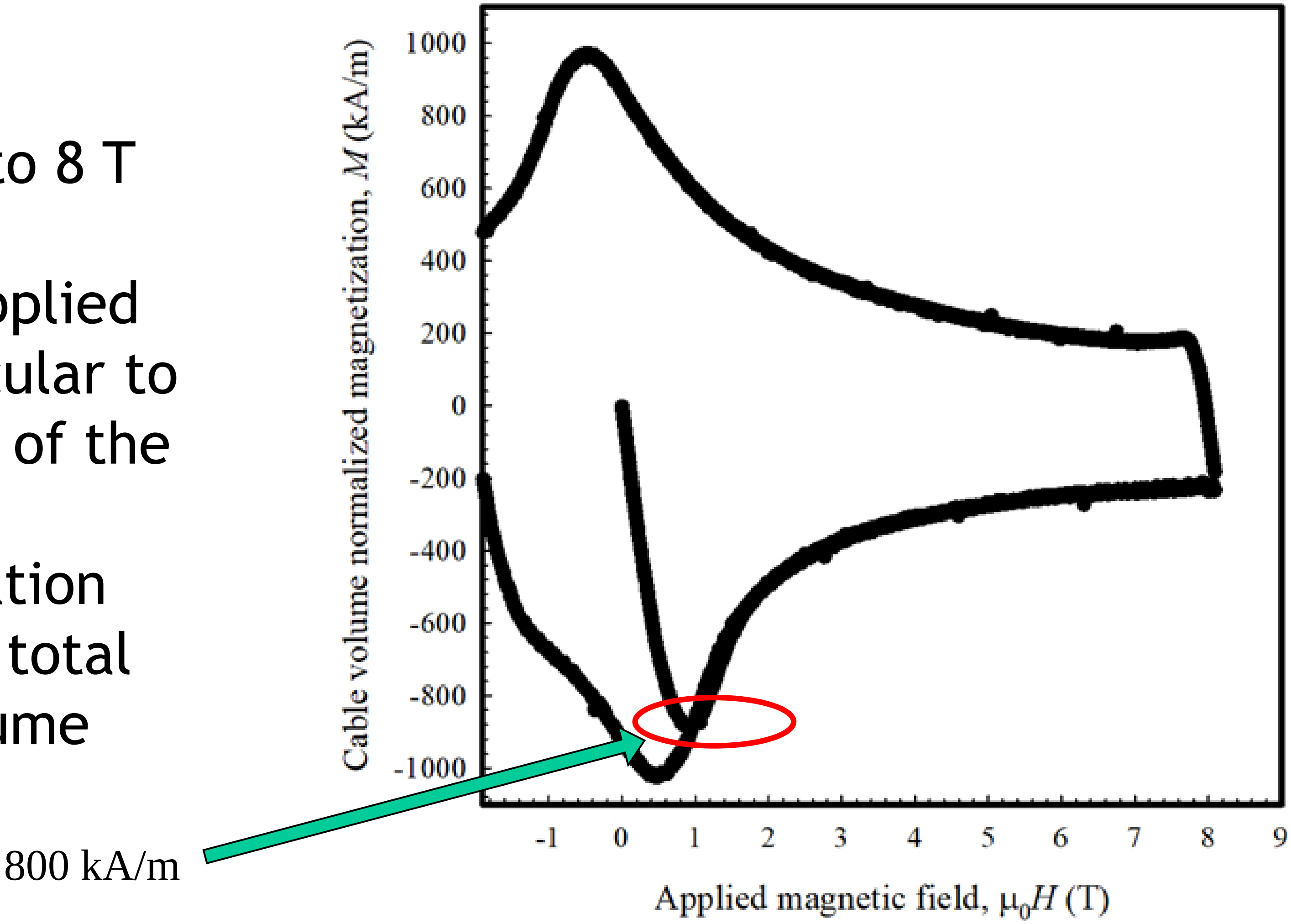
M-H of CORC ± 4 T

- B_{max} = 4.5 T.
- Field is applied perpendicular to the *z*-axis of the cables
- Normalization volume is total cable volume



M-H of CORC -2 T to 8 T

- *M-H* -2 T to 8 T sweep
- Field is applied perpendicular to the *z*-axis of the cables.
- Normalization volume is total cable volume

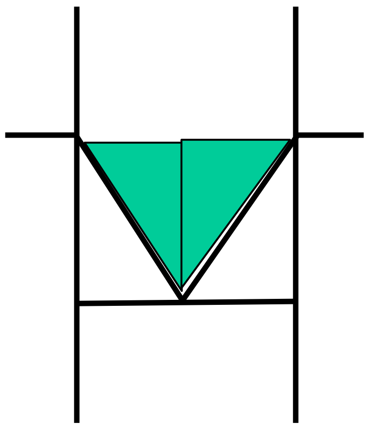


Application to field error in accelerators

- Results not yet been put into field error calculations for magnets, will be magnet geometry dependent
- Nevertheless, some value for simply imagined "replacing" a NbTi or Nb_3Sn winding
- Taking the LHC as a reference, $b_3 \cong 3$, $M_{h,cable,1.9K,0.54T}$ = 10.3 kA/m
- Nb_3Sn deff 10 X that of NbTi, b_3 10 X higher $\cong$ 30-40 units.
- For HTS cable, $M_{inj} \cong$ 600-900 kA/m, suggesting b_3 values around **300 units** for a direct replacement (the current density at collision is roughly similar for these cables at their point of operation, so no correction is added for that).
- This is a very simple and rough estimate, and assumes no changes in the magnet to minimize these effects. As such, it is merely a starting point of data for inclusion in magnet design.

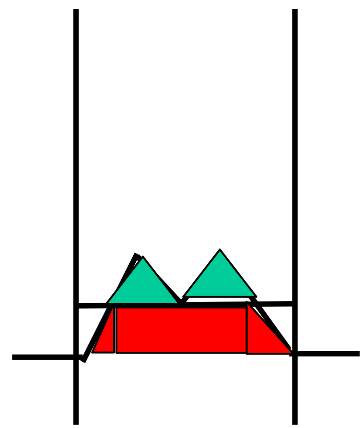
Use of a modified pre-cycle to reduce magnetization

0 T →5T ("collision") → 0 T → 1 T (inj)

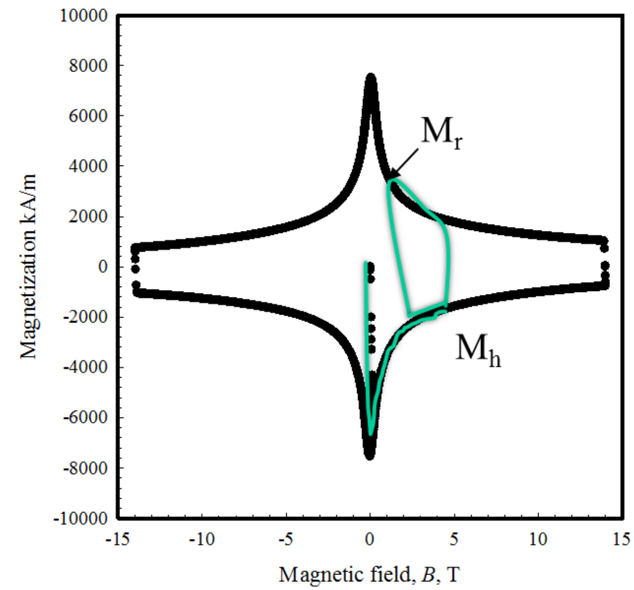


$M_{inj} \propto$ green area
$M_{inj}(t) \propto (A_G)^*(1-Ln(t))$

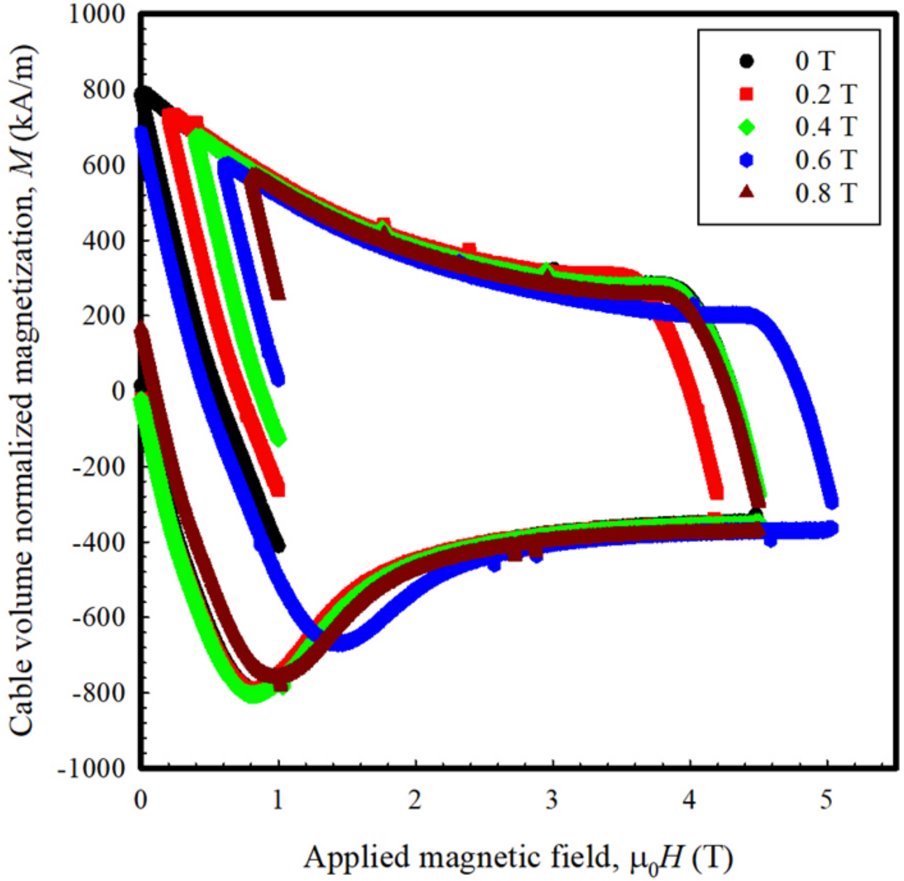
0 T →5T ("collision") → Mr (0-1 T) → 1 T (inj)



$M_{inj} \propto$ green area-red area
$M_{inj}(t) \propto (A_G-A_R)^*(1-Ln(t))$



M-H of CORC Sample with different Pre-injection cycles



see 1MPo2C-03 (Cory Myers)

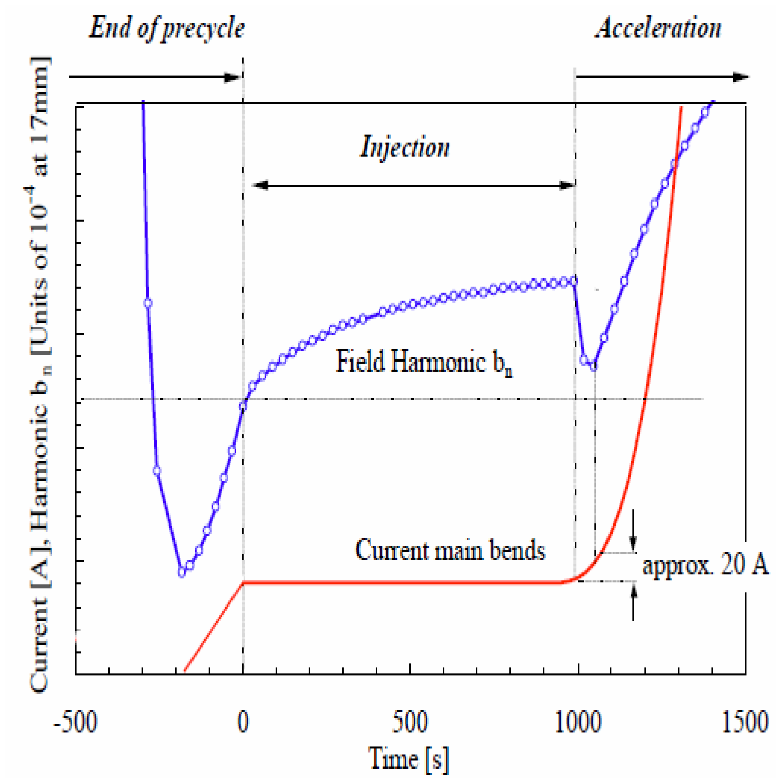
Sample type /hold field	M_0 (kA/m)
CORC 0 T	-430
CORC 0.2 T	-280
CORC 0.6 T	19
CORC 0.8 T	180

Drift on the injection Porch

REQUIREMENTS FOR REAL TIME CORRECTION OF DECAY AND SNAPBACK IN THE LHC SUPERCONDUCTING MAGNETS

T. Wijnands, M. Lamont, A. Burns, L. Bottura, L. Vos,
CERN, Geneva, Switzerland

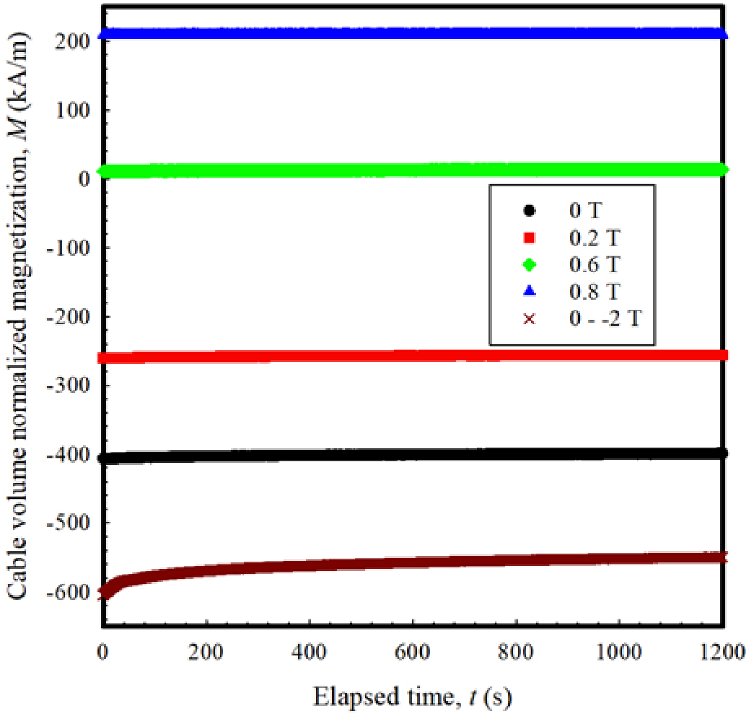
- Just as important as the absolute value of b_3 is any ***change with time*** during the injection porch
- It is possible to compensate for error fields with corrector coils, but the presence of ***drift*** makes this much more difficult
- At right is shown the drift of the error fields as a function of time from zero to 1000 seconds for LHC magnets, followed by a snap-back once the energy ramp begins
- The underlying mechanism for drift in NbTi magnets is the decay of coupling currents, (especially inhomogeneous and long length scale coupling currents) and their influence on the strand magnetization

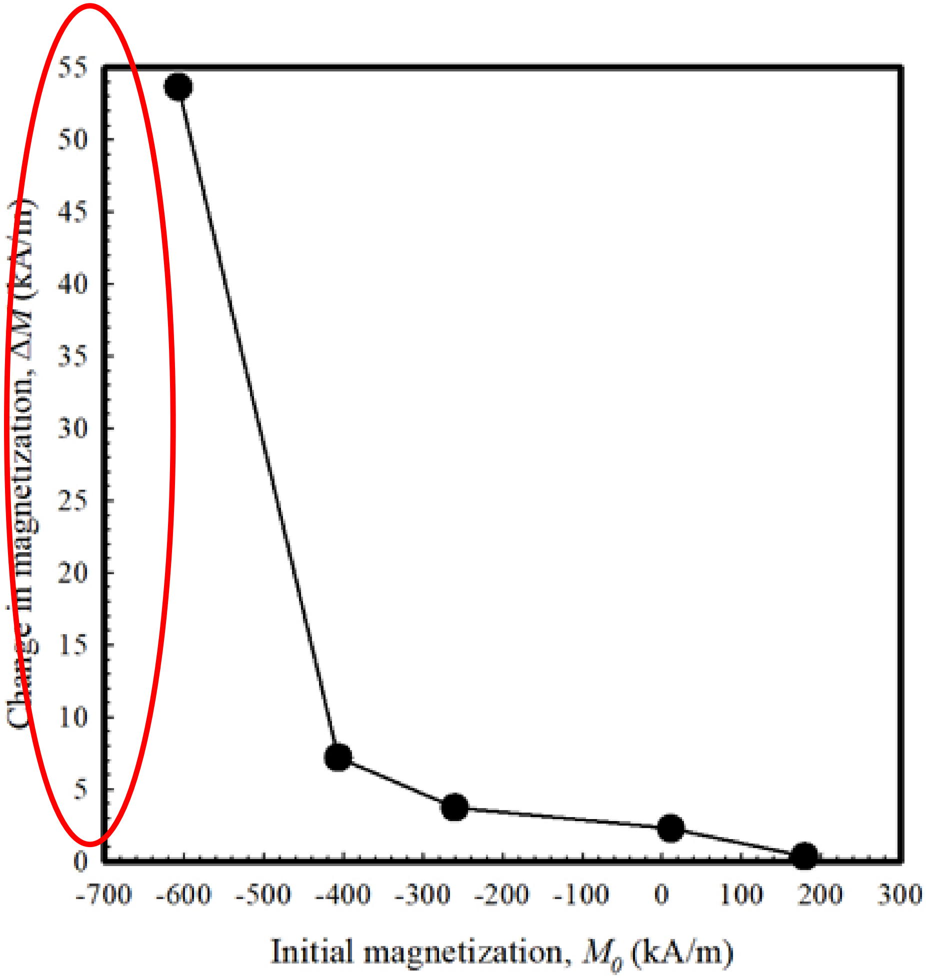


Need to keep both b_3 and its drift below 1 unit
For NbTi and Nb_3Sn based magnets, this is possible

Drift in the magnetization

HTS materials suffer significant flux creep
This will lead to decay in the magnetization, see 1MPo2C-03 (Cory Myers)





Summary

- A hall probe susceptometer for the measurement of HTS/LTS cables at 4 K and in fields of up to 12 T has been developed
- *M-H* measurements were performed on a CORC cable sample at $\pm$ 4.5 T, as well as -2T to 8 T
- Also shown were the Magnetization results for different cycles mimicking pre-injection cycles
- Collaboration with LNBL to provide magnetization on cables used in Canted Cos magnets
- Magnetization levels for HTS cables, as expected, can be high, with potential high field errors, to be mitigated by magnet design
- Drift in the magnetization to flux creep significant, more (4 X?) the total magnetization of NbTi, and about the total magnetization of Nb_3Sn